
Connecticut River Flood Investigation

April 1990



**US Army Corps
of Engineers**
New England Division

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE April 1990		3. REPORT TYPE AND DATES COVERED Flood Plain Management Services
4. TITLE AND SUBTITLE Connecticut River Flood Investigation			5. FUNDING NUMBERS	
6. AUTHOR(S) U.S. Army Corps of Engineers New England Division				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers, New England Division 424 Trapelo Road Waltham, MA 02254-9149			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Connecticut Department of Environmental Protection State of Connecticut			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES This study was prepared under the Flood Plain Management Services (FPMS) program. Section 206 Flood Control Act of 1960, Public Law 86-645.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release Distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report assessed the previously developed peak discharge frequency curve for the lower Connecticut River. The concern was that the high flows experienced in 1984 and 1987 may alter this curve and thus impact the magnitude of the estimated 100 year peak flow used in previous studies. This study addressed the peak discharge frequency curve by performing a gage analysis at Middleton, CT. (Bodkin Rock gage) using the flow record from 1838 through 1988 and then taking a sensitivity analysis of the estimated discharge frequency curve. The modified discharge frequency curve developed is considered hydrologically similar to the one that was developed in the 1960's. The previous estimate of the 100 year flow of approximately 185,000+ cfs is considered reasonable. A HEC-2 model for a continuous run of the lower Connecticut River is created from the previous HEC-2 models developed by Anderson-Nichols, Inc. for the Federal Emergency Management Agencies (FEMA) Flood Insurance Studies (FIS) for the east bank communities from Portland to Enfield. This continuous model is run for the 100 year flow and checked by comparing computed water surface elevations to those previously published in the Flood Insurance Studies.				
14. SUBJECT TERMS HEC-2; Connecticut River; Bodkin Rock gage; flood control			15. NUMBER OF PAGES 42	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

CONNECTICUT RIVER FLOOD INVESTIGATION

prepared for
State of Connecticut

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

APRIL 1990

EXECUTIVE SUMMARY

This report is prepared under the floodplain management program at New England Division at the request of the Connecticut Department of Environmental Protection.

The peak discharge frequency curve for the lower Connecticut at Middletown, Connecticut (Bodkin Rock gage) is assessed in this study. The modified discharge frequency curve developed is considered hydrologically similar to the frequency curve developed in the 1960's. The previous estimate of the 100-year flow of approximately 185,000+ cfs is considered reasonable.

A HEC-2 input data file for a continuous run of the lower Connecticut River from Portland to Enfield is created from the previous HEC-2 models developed by Anderson-Nichols, Inc. for the Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS). This continuous model is run for the 100-year flow and checked by comparing computed water surface elevations to those previously published in the Flood Insurance Studies. The model is also run for the State of Connecticut Encroachment Line Program design flow. This HEC-2 input file is available to the Connecticut Department of Environmental Protection.

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INTRODUCTION

STUDY AUTHORITY

This study was prepared under the Flood Plain Management Services program (FPMS). The FPMS program is authorized under Section 206 of the Flood Control Act of 1960 (PL 86-645) which states

"...The Secretary of the Army, through the Chief of Engineers, Department of the Army, is hereby authorized to compile and disseminate information on floods and flood damages...general criteria for guidance in the use of flood plain areas and to provide engineering advice to local interests for their use in planning to ameliorate the flood hazard..."

This program allows the Corps to provide planning and technical assistance to states, regional authorities, and communities. The FPMS program is funded each fiscal year by a line item in the Corps' General Investigation budget. Each year NED staff members meet with officials representing Connecticut, Massachusetts, Rhode Island, Vermont, New Hampshire, and Maine to determine which projects the states are interested in, to establish project priorities, and to develop the scopes for the projects.

In a meeting with staff members from the Connecticut Department of Environmental Protection on 28 November 1988, NED was requested to study selected floodplain management issues for the Connecticut River. A meeting was held with representatives from the Connecticut DEP on 27 November 1989 to review study progress. This is the final report on the project.

STUDY PURPOSE

At the November 1989 meeting the Connecticut Department of Environmental Protection (DEP) requested NED investigate several issues related to floodplain management on the Connecticut River. It was requested that NED review the previously developed peak discharge frequency curve for the lower Connecticut River. The DEP was concerned that the high flows experienced in 1984 and 1987 may alter this curve and thus impact the magnitude of the estimated 100-year peak flow used in previous studies. The 100-year flood flow is used in the Federal Emergency Management Agency (FEMA) published Flood Insurance Studies (FIS).

The DEP also requested that NED provide a continuous HEC-2 model for the Connecticut River from Middletown to the Connecticut/Massachusetts border based on data used for the Federal Emergency Management Agency published Flood Insurance Studies for the communities along this portion of the Connecticut River. The DEP plan to use this HEC-2 model in their floodplain management program. During the review meeting in November 1989 it was requested that this compiled HEC-2 model be run for the 283,000 cfs design flow used in establishing the State of Connecticut Encroachment Lines.

The State of Connecticut Encroachment lines were established in 1959 by the Water Resources Commission under authority of the Connecticut State Legislature. These stream encroachment lines delineate an area which should not be encroached upon without authorization.

The DEP also requested that NED provide an assessment of the adequacy of the East Hartford Dike to protect new development in East Hartford and that NED assess recently proposed structural modifications to the dike.

STUDY SCOPE

The requested review of peak discharge frequency curve for the lower Connecticut is addressed in this study by performing a gage analysis at Middletown, Connecticut (Bodkin Rock gage) using the the flow record from 1838 through 1988 and performing a sensitivity analysis of the estimated discharge frequency curve.

The requested HEC-2 model for a continuous run of the lower Connecticut River is created from the previous HEC-2 models developed by Anderson-Nichols, Inc. for the Federal Emergency Management Agencies (FEMA) Flood Insurance Studies (FIS) for the east bank communities from Portland to Enfield. Model data including flows, cross section information, Manning "n" values, and encroachment stations are compiled from the FIS backup information and entered into a HEC-2 input file. This continuous model is run for the 100-year flow and checked by comparing computed water surface elevations to those previously published in the Flood Insurance Studies. The model is also run for the State of Connecticut Encroachment Line Program design flow. This HEC-2 input file is available to the Connecticut DEP.

An assessment of the adequacy of the East Hartford dike and the impact to the dike's integrity due to development on or adjacent to the dike is not addressed in this study. However, the issue of the level of protection provided by this local protection project is assessed in a separate study published in December 1989 by NED.(1) The issue of the dikes integrity is more appropriately addressed by our Operations Division who inspect all local protection projects on an annual basis to insure the project's integrity. A letter from New England Division to the DEP dated 3 February 1989 relative to this issue is included as Appendix A.

PREVIOUS STUDIES

Past studies prepared by the Army Corps of Engineers, State of Connecticut, and Federal Emergency Management Agency (FEMA) that contain information on the Connecticut River floodplain from Bodkin Rock to the Massachusetts state line include the following reports:

Connecticut River Basin - Comprehensive Water and Related Land Resources Investigation, 1970;

Report on Stream Encroachment Lines - Connecticut River - Bodkin Rock to Massachusetts State Line, 1959;

Flood Insurance Studies published by FEMA for the east bank communities of Portland (1978), Glastonbury (1977), East Hartford (1979), South Windsor (1988), East Windsor (1977), Enfield (1978), and the west bank communities of Middletown (1980), Cromwell (1977), Rocky Hill (1977), Wethersfield (1982), Hartford (1986), Windsor (1988), Windsor Locks (1977), and Suffield (1979).

HYDROLOGY

BACKGROUND

The request to review the previously developed discharge frequency curve for the lower Connecticut River resulted from two recent flood events, namely May/June 1984 and March/April 1987. The Connecticut DEP and USGS (United States Geological Survey, telecom with Mr. Larry Weiss, October 1988) were concerned that these events might change the previously calculated 100-year peak flow on the lower Connecticut River. Also the Connecticut DEP was concerned that decreases in natural valley storage due to building in the floodplain throughout the Connecticut River basin might also have effected the the magnitude of the peak flow.

METHODOLOGY

In order to examine the impact of the recent flood events on the discharge frequency curve previously developed by the Corps at the Middletown gage (Bodkin Rock) the new flow information is added and a sensitivity analysis performed. This analysis was conducted by the Water Control Branch, Division of Engineering at NED. Portions of this review are presented here and the full report is included as Appendix B. The discharge frequency curve at Middletown is assessed for both natural (unmodified by flood control reservoirs) and modified (conditions with reservoirs).

NATURAL DISCHARGE FREQUENCIES

Previous analysis of flow records at Middletown were made in the mid-1960's for the then available 123 years of systematic flow records plus records of historic flood events that occurred in 1683, 1692, 1801, and 1828. Natural and modified discharge frequency curves were developed at this time using statistical analysis of this 127 years of flow data.

In this study the gage analysis previously calculated is updated to include the now available 147 years of systematic flow data (1838-1988) plus the 4 historic flood events for a total of 151 years of systematic flow records. This longer data set contains computed natural 1987 and 1984 flows since the flood control reservoirs were operational at this time. Results indicate less than a 1 percent increase in the 100-year peakflow as determined during the sixties analyses. Sensitivity tests of the data set also indicated the insignificant impact of the 1984 and 1987 events. The computed natural discharge frequency curve is included in Appendix B.

MODIFIED DISCHARGE FREQUENCIES

Since the floods of record experienced on March 1936 and September 1938 the Corps has constructed a system of 16 flood control reservoirs. Typical flood reductions provided by this system will vary depending on the storm orientation.

Modified discharge frequencies were previously developed by NED to reflect conditions with the 16 flood control reservoirs in place. Based on this previous analyses by NED of a typical flood over the entire river basin the average reduction in peak discharges at Middletown is considered approximately 21 percent. However, some reductions will be greater and some less depending on the storm orientation with respect to the upstream reservoirs. The adopted modified frequency curve is presented in Appendix B and represents the expected average reduction for a wide range of floods. This type of approximation is usually used to provide a hydrologic basis for economic analyses of flood control measures.

As a check on the adopted modified discharge frequency curve the period of record since the last flood control reservoir was placed in operation is analyzed (1970-1988). Results of analysis indicate a 100-year discharge about 3 percent greater than the modified discharge frequency curve shown in Appendix B. During this period the 1984 flood event was experienced and has a notable effect on the short period of record (19 years) used in this check. Based on the analysis the adopted modified discharge frequency curve is considered reasonable.

STATISTICAL CONFIDENCE LIMITS

The estimated discharge frequency curve is only an approximation based on the data set analyzed and this estimate has associated with it an inherent variability. As an estimate of the expected variability associated with the calculated curve confidence limits can be constructed. The five and ninety-five percent confidence limits are determined for the computed natural Connecticut River discharge frequency curve. For the purposes of this study it is then assumed that the adopted modified discharge frequency curve would have the same percent deviation in peak flows and the confidence limits are estimated for the modified curve as shown in Appendix B. This analysis indicates that there is a ninety-five percent probability that the 100 year discharge at Middletown is greater than 170,000 cfs and a ninety-five percent probability that the 100 year discharge at Middletown is not greater than 205,000 cfs. The previously developed modified 100-year discharge of 185,000 \pm cfs at Middletown is midway between the computed confidence limits.

SUMMARY

Based on the above analysis the modified discharge frequency curve developed in this study is considered hydrologically similar to the frequency curve developed in the 1960's. The occurrence of the 1984 and 1987 floods in recent years has had no significant impact on the long term flow frequency relationship at the Middletown gage.

MODELING THE LOWER CONNECTICUT RIVER USING HEC-2

BACKGROUND

The HEC-2 computer model provides computed water surface elevations at modeled cross sections for given flow values. The HEC-2 computer program was developed by the Hydrologic Engineering Center in Davis, California. A one page description of the HEC-2 computer program is included as Appendix C.

The HEC-2 computer program requires input data which characterizes the study area. The HEC-2 model of the lower Connecticut River is established using existing HEC-2 input data. The Connecticut River from Bodkin Rock to Enfield had previously been modeled using HEC-2 in the late 70's by Anderson Nichols, Inc. on a community by community basis for the Federal Emergency Management Agency's (FEMA's) Flood Insurance Studies (FIS's) Program.

STUDY AREA

The compiled HEC-2 model represents the Connecticut River from Bodkin Rock at Middletown to the Connecticut/Massachusetts state line (Figure 1), approximately 43 river miles. The east bank communities are Portland, Glastonbury, East Hartford, South Windsor, East Windsor, Enfield, and the west bank communities are Middletown, Cromwell, Rocky Hill, Wethersfield, Hartford, Windsor, Windsor Locks, and Suffield.

METHODOLOGY

In order to compile the existing cross section data and other required HEC-2 input data the FIS studies, files held at the DEP, Water Resource Unit, and microfiche files at NED were examined.(2) A comparison of the east bank community FIS information to the west bank community FIS information is provided in Table 1. No significant discrepancies in the east bank water surface elevations compared to the west bank elevations or upstream compared to downstream were noted. There were some differences in cross section stationing. The cross section data, bridge data, and Mannings "n" values used are from the input files for the east bank communities.

The Connecticut River cross section HEC-2 input data was prepared for the flood insurance studies using topographic mapping with 2 to 5 foot contour intervals for valley portions, field measurement of below water portions, and bridge plans or field survey for bridges.(3)

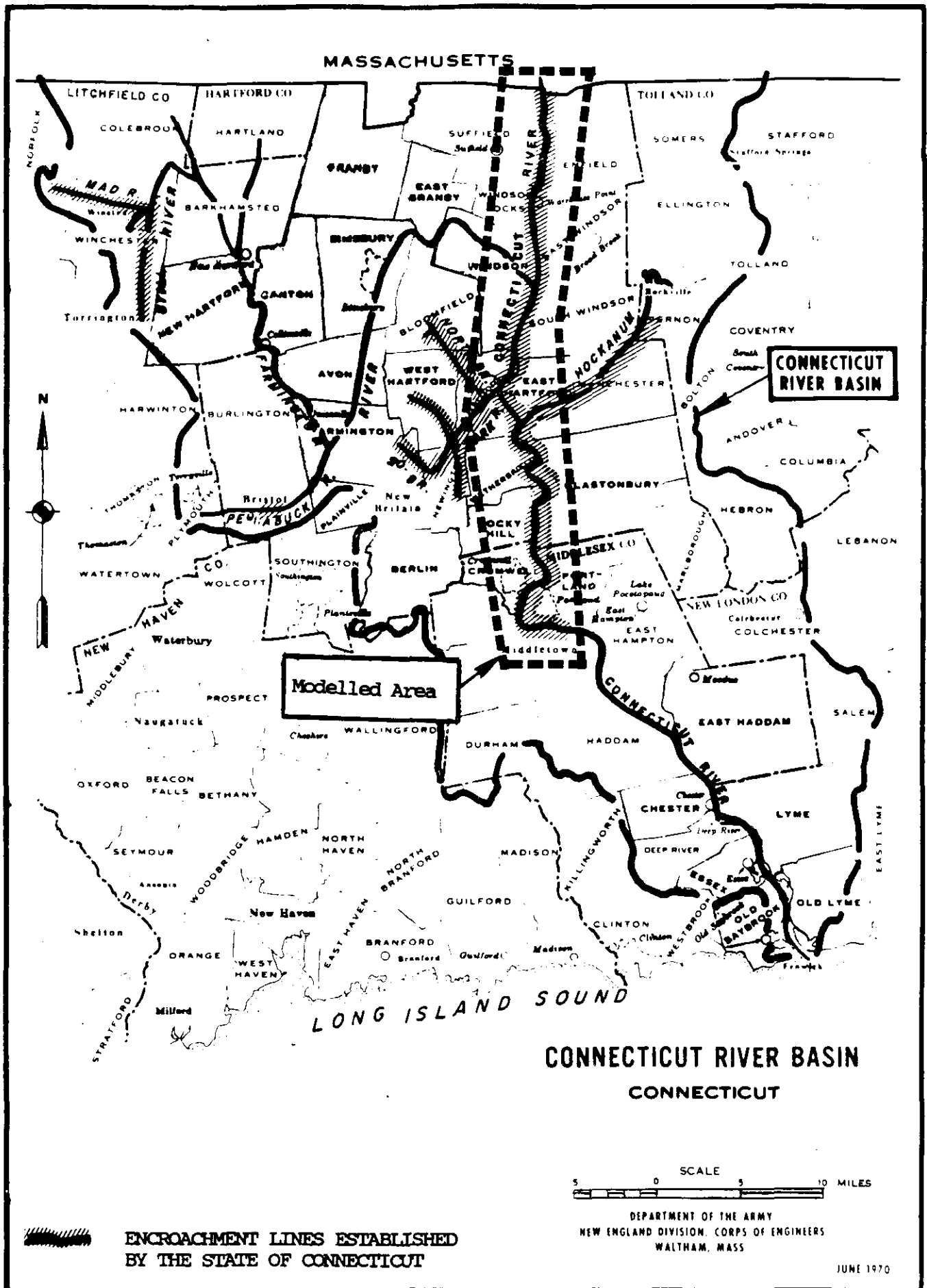


Table 1. Comparison of FEMA published FIS base flood elevations for Communities along the Lower Connecticut River

River Miles	East Bank Community	FIS X-sec	West Bank Community	FIS X-sec	NOTES	published 100-year flood elevations		
						East Bank Comm.	West Bank Comm.	Difference
27.050	PORTLAND	A	MIDDLETOWN		Middletown stationing was done from	20.6		
27.947		B		C	corporate boundary while Portland stationing	20.9	20.9	0
28.465		C		D	was done from the river's mouth	21.0	21.0	0
28.920		D		F		21.8	21.9	-0.1
29.825		E		G	Middletown hydraulic analysis completed in 1975,	22.1	22.2	-0.1
30.427		F			study published in 1980	22.4		
31.025		G		I		22.9	23.0	-0.1
31.555		I		J	Portland hydraulic analysis completed in 1977,	23.1	23.3	-0.2
32.030		J	CROMWELL	A	study published in 1978	23.3	23.3	0
32.800		K		B		23.8	23.8	0
33.400		L		C	Cromwell study published in 1977	24.1	24.0	0.1
34.260				D			24.6	
34.734		N		E		25.0	25.0	0
35.462		O		F		25.0	25.0	0
36.562		P		G		26.3	26.3	0
37.080	GLASTONBURY	A	ROCKY HILL	A	Glastonbury published in 1977	26.5	26.5	0
37.927		B		B		26.8	26.8	0
38.924		C		C	Rocky Hill hydraulic analysis completed in 1977,	27.0	27.0	0
39.691		D		D	study published in 1980	27.0	27.0	0
40.389		E		E		27.0	27.0	0
41.194		F		F		27.1	27.1	0
42.535		G	WETHERSFIELD	A(1.24)	Wethersfield stationing was done from	27.6	27.4	0.18
44.086		H		B(2.81)	coporate boundary	27.9	27.9	-0.02
45.522		I		C(4.22)	Wethersfield hydraulic analyses completed in 1976,	28.1	28.1	-0.02
45.607				D(4.3)	study published in 1982		28.3	
45.681		J		E(4.37)		28.2	28.5	-0.32
46.302		K		F(5.02)		28.3	28.7	-0.42

Table 1 (continued). Comparison of FEMA published FIS base flood elevations for Communities along the Lower Connecticut River

River Miles	East Bank Community	FIS X-sec	West Bank Community	FIS X-sec	NOTES	published 100-year flood elevations		
						East Bank Comm.	West Bank Comm.	Difference
46.676	EAST HARTFORD	A	HARTFORD		Hartford study published in 1978, revised 1986	28.8		
47.703		B		FIS		29.1		
48.662		C		X-sec	East Hartford hydraulic analyses completed in 1977,	29.4	not available	
48.885		D		not available	study published in 1979	29.4		
49.712		E				29.8		
49.846		F				29.8		
50.008		G				29.8		
50.710		H				30.3		
50.794		I				30.3		
51.612		J				30.4		
52.494		K				30.8		
53.521	SOUTH WINDSOR	A	WINDSOR	A	South Windsor hydraulic analyses completed in 1978,	31.1	31.1	0
53.568				B	study published in 1980, revised 1986		31.2	
53.630		B				31.2		
54.822		C		C	Windsor hydraulic analyses completed in 1977,	31.7	31.7	0
56.007		D			study published in 1977, revised 1986	32.0		
56.774		E		D		32.2	32.2	0
57.683	EAST WINDSOR			E	East Windsor study published in 1977		32.3	
58.436		A		F		32.5	32.5	0
59.047		B		G		32.7	32.7	0
60.197		C	WINDSOR LOCKS	A	Windsor Locks hydraulic analyses completed in 1977,	33.1	33.1	0
60.992		D		B	study published in 1978	33.4	33.4	0
61.100		E		C		33.6	33.6	0
61.806		F		D		33.9	33.9	0
61.930		G		E		34.2	34.2	0
62.280				F			34.7	
63.090	ENFIELD	A	SUFFIELD	A	Enfield hydraulic analyses completed in 1978,	35.7	35.7	0
64.040		B		B(64.058)	study published in 1978	37.8	37.8	0
64.770		C		C(64.772)		39.0	39.1	-0.1
65.357		D			Suffield hydraulic analyses completed in 1977,	42.9		
65.379				D(65.372)	study published in 1979		42.9	
66.160		E				49.4		
66.414		F		E(66.414)		50.7	50.7	0
67.113				F(67.112)			53.1	
67.142		G				53.4		
67.944		H		G(67.940)		54.4	54.4	0
68.679		I		H(68.678)		55.1	55.1	0
69.338				I(69.338)			56.8	

This existing cross section information was checked against the Metropolitan District Commission available 2-foot contour maps for Portland, Glastonbury, East Hartford, and South Windsor.(4) No significant changes were noticed between the existing input data and the mapping. However, if the DEP is aware of areas where cross sections may have changed since the Anderson-Nicholas modeling effort they may want to include these changes in the model. The approximate location of the cross sections used are shown on plates 1 through 5. Cross section spacing (reach length) along the river channel ranges from approximately 1,000 feet to 8,000 feet. Cross sections are closer at bridges. Reach length information is included in Table 2.

There are twelve bridges across the Connecticut River between Portland and Enfield. Eleven of these bridges are included in the compiled HEC-2 model. Three of these bridges are modeled using the special bridge method, the Conrail Bridge in Portland, the Conrail Bridge in East Hartford, and the Route 140 bridge in East Windsor (see Appendix C for special and normal bridge explanation). At two of the bridges the Route 190 bridge and the Conrail Bridge in Enfield only the bridge piers are modeled. Six bridges are modeled using the normal bridge method. The location and low chord elevation of the bridges are included in Table 2. The Arrigoni bridge, located at river mile 31.25, in Portland is not modeled. This bridge consists of two trussed arch spans which provide a clear wide opening. The low chord is 93 feet providing vertical clearance.

The 100-year discharges used in the model are the same as the discharges used in the FIS studies. The flows used for the 100-year are shown in Table 2. These specified flows are easily changed in the input file at the discretion of the user if desired. The starting water surface elevation for the 100-year flow is from the FIS for Portland.

The model also contains a set of encroachment stations at each cross section which are used in the Flood Insurance Studies to aid in determination of the river floodway. The FIS floodway is defined as the channel of the river and the adjacent land areas that if encroached on may result in increasing the calculated 100-year flood surface elevation more than one foot. The starting water surface elevation for this run is the 100-year starting water surface elevation plus one foot.

At the request of the DEP the State Encroachment Line design flow of 283,000 cfs was also included. The starting water surface elevation for this discharge was taken from the profile in the report on the "Connecticut Stream Encroachment Lines".(5)

RESULTS

The HEC-2 Water Surface Profiles computer program was run for the 100-year flood event. The resulting calculated water surface elevations are compared to the values published in the FIS studies for the communities and to the previous HEC-2 output contained in the microfiche files. This check of the model output was used to verify that the input data as compiled provided the same results as the model which was originally developed for FEMA. The comparison of the output is provided in

Table 2. Comparison of FIS 100-year Flood Elevations and HEC-2 output

Cross Sections FEMA, FIS	River Miles	Reach Length (ft)	Elevations	HEC-2	HEC-2	(3)-(2)	(3)-(1)	100-year flow at X-sec (cfs)
			Published	output	output			
			in FEMA, FIS (ft) Column 1	Anderson- Nichols (ft) Column 2	This study (ft) Column 3			
<hr/>								
Portland	26.081	0		19.80	19.80	0.0		186000
A	27.050	5116	20.6	20.48	20.48	0.0	-0.1	186000
B	27.947	4736	20.9	20.89	20.89	0.0	-0.0	186000
C	28.465	2735	21.0	21.22	21.22	0.0	0.2	186000
	28.600	712		21.71	21.71	0.0		186000
	28.800	1056		21.79	21.79	0.0		186000
D-Bodkin Rock gage	28.920	634	21.8	21.84	21.84	0.0	0.0	186000
E	29.825	4778	22.1	22.11	22.11	0.0	0.0	186000
F	30.427	3178	22.4	22.53	22.52	0.0	0.1	186000
G	31.025	3157	22.9	22.67	22.67	0.0	-0.2	186000
	31.059	180		22.68	22.68	0.0		186000
Conrail Bridge	31.065	31		22.76	22.75	0.0		186000
low chord 27.4	31.119	285		22.79	22.79	0.0		186000
I	31.555	2302	23.1	23.23	23.23	0.0	0.1	186000
J	32.030	2508	23.3	23.54	23.54	0.0	0.2	186000
K	32.800	4066	23.8	23.80	23.80	0.0	0.0	186000
L	33.400	3170	24.1	24.06	24.06	0.0	-0.0	186000
	34.260	4540		24.55	24.55	0.0		186000
M	34.734	2503	25.0	24.95	24.95	0.0	-0.1	186000
O	35.462	3844	25.0	25.02	25.01	0.0	0.0	186000
P	36.562	5810	26.3	26.30	26.30	0.0	0.0	186000
A-Glastonbury	37.080	2735	26.5	26.50	26.50	0.0	0.0	186000
B	37.927	4472	26.8	26.85	26.85	0.0	0.1	186000
C	38.924	5264	27.0	27.26	27.26	0.0	0.3	186000
D	39.691	4050	27.0	27.63	27.63	0.0	0.6	186000
E	40.389	3685	27.0	27.70	27.70	0.0	0.7	186000
F	41.194	4250	27.1	27.77	27.77	0.0	0.7	186000
G	42.535	7080	27.6	27.83	27.83	0.0	0.2	186000
H	44.086	8139	27.9	27.96	27.96	0.0	0.1	186000
I	45.522	7580	28.1	28.09	28.09	0.0	-0.0	186000
	45.593	380		28.11	28.11	0.0		186000
Putnam Memorial Brid	45.594	1		28.06	27.99	-0.1		186000
low chord 60.0	45.607	69		28.06	28.00	-0.1		186000
	45.608	1		28.22	28.32	0.1		186000
J	45.681	391	28.2	28.23	28.33	0.1	0.1	186000
K	46.302	3279	28.3	28.30	28.39	0.1	0.1	186000

Remarks:

100 year elevations published in FIS for Portland were adjusted to match Middleton FIS.

Table 2. Comparison of FIS 100-year Flood Elevations and HEC-2 output
CONTINUED

Cross Sections FEMA, FIS	River Miles	Reach Length (ft)	Elevations HEC-2 in FEMA, Anderson-		HEC-2 This study		100-year flow at X-sec (cfs)	
			FIS (ft)	Nichols (ft)	(ft)	(ft)	(3)-(2)	(3)-(1)
			Column 1	Column 2	Column 3	(3)-(2)	(3)-(1)	(cfs)
A-East Hartford	46.676	1975	28.8	28.35	28.45	0.1	-0.4	186000
B	47.703	5420	29.1	28.45	28.54	0.1	-0.6	185500
C	48.662	5060	29.4	28.90	28.99	0.1	-0.4	185500
	48.757	510		28.94	29.03	0.1		185500
Charter Oak Bridge	48.758	1		28.91	28.99	0.1		185500
low chord 88.0	48.770	65		28.92	29.00	0.1		185500
	48.771	1		28.95	29.06	0.1		185500
D	48.885	610	29.4	29.01	29.12	0.1	-0.3	185500
E	49.712	4370	29.8	29.29	29.39	0.1	-0.4	185500
	49.797	455		29.34	29.44	0.1		185500
Founders Bridge	49.798	1		29.23	29.33	0.1		185500
low chord 53.0	49.815	90		29.25	29.35	0.1		185500
	49.816	1		29.37	29.48	0.1		185500
F	49.846	165	29.8	29.39	29.50	0.1	-0.3	185500
G-gaging station	50.008	860	29.8	29.86	29.97	0.1	0.2	185500
	50.054	250		29.87	29.98	0.1		185500
Buckeley Memorial Br	50.055	1		29.82	29.93	0.1		185500
low chord 46.0	50.079	125		29.84	29.95	0.1		185500
	50.080	1		30.19	30.30	0.1		185500
	50.152	385		30.21	30.31	0.1		185500
H	50.710	2950	30.3	30.26	30.37	0.1	0.1	185500
	50.740	160		30.27	30.38	0.1		185500
	50.750	50		30.18	30.29	0.1		185500
Conrail Bridge	50.755	25		30.19	30.30	0.1		185500
low chord 32.4	50.765	50		30.43	30.53	0.1		185500
I	50.794	155	30.3	30.43	30.54	0.1	0.2	185500
J	51.612	4320	30.4	30.69	30.80	0.1	0.4	185500
K	52.494	4660	30.8	30.98	31.08	0.1	0.3	185500
South Windsor	53.060	2990		31.11	31.21	0.1		185500
A	53.521	2430	31.1	31.11	31.21	0.1	0.1	185500
	53.568	250		31.13	31.23	0.1		185500
J. Bissel Memorial Br	53.576	1		31.12	31.21	0.1		185500
low chord 49.5	53.582	70		31.12	31.22	0.1		185500
	53.585	1		31.17	31.28	0.1		185500
B	53.630	240	31.2	31.19	31.30	0.1	0.1	185500
C-below Farmington R	54.822	6290	31.7	31.75	31.85	0.1	0.2	185500
D-above Farmington R	56.007	6290	32.0	32.02	32.12	0.1	0.1	185000
E	56.774	4050	32.2	32.17	32.26	0.1	0.1	185000
East Windsor	57.683	4800		32.34	32.43	0.1		185000
A	58.436	3975	32.5	32.49	32.58	0.1	0.1	185000
B	59.047	3225	32.7	32.71	32.79	0.1	0.1	185000
C	60.197	6070	33.1	33.13	33.21	0.1	0.1	185000
D	60.992	4200	33.4	33.44	33.52	0.1	0.1	185000
	61.040	250		33.46	33.53	0.1		185000
Interstate 91 Bridge	61.042	5		33.39	33.46	0.1		185000
low chord 48.0	61.059	90		33.41	33.48	0.1		185000
	61.061	5		33.58	33.66	0.1		185000
K	61.100	205	33.6	33.59	33.67	0.1	0.1	185000
F	61.806	3730	33.9	33.87	33.95	0.1	0.1	185000
	61.900	500		33.99	34.06	0.1		185000
	61.903	5		33.96	34.03	0.1		185000
Route 140 Bridge	61.909	30		34.14	34.23	0.1		185000
low chord 34.0	61.912	5		34.21	34.29	0.1		185000
G	61.930	100	34.2	34.23	34.31	0.1	0.1	185000
	62.280	1850		34.74	34.82	0.1		185000

100 year elevations published in FIS for Glastonbury were adjusted to match Wethersfield FIS.

100 year elevations published in FIS for East Hartford were adjusted to match Hartford FIS.

Table 2. Comparison of FIS 100-year Flood Elevations and HEC-2 output
CONTINUED

CONTINUED

Cross Sections FEMA, FIS	River Miles	Reach Length (ft)	Elevations	HEC-2	HEC-2	100-year flow at X-sec (cfs)
			Published output in FEMA, FIS (ft)	output Anderson- Nichols (ft)	output This study (ft)	
			Column 1	Column 2	Column 3	
			(3)-(2)	(3)-(1)		

Enfield	63.062	4130		35.50	35.57	185000
	63.075	89		35.59	35.65	185000
Conrail Bridge	63.076	0.09		35.56	35.62	185000
low chord 59	63.080	40		35.59	35.65	185000
	63.081	0.09		35.70	35.77	185000
A	63.090	50	35.7	35.72	35.79	185000
	63.309	1150		36.43	36.49	191000
B	64.040	3859	37.8	37.78	37.83	191000
	64.348	1626		39.11	39.15	191000
C	64.770	2228	39.0	39.05	39.08	191000
D	65.357	3070	42.9	42.92	42.93	191000
	65.367	50		43.11	43.12	191000
	65.368	0.09		42.69	42.69	191000
	65.379	40		43.03	43.03	191000
	65.380	0.09		44.41	44.41	191000
	65.392	50		44.53	44.53	191000
E-below Enfield Dam	66.160	3930	49.4	49.36	49.36	191000
	66.344	960		50.13	50.13	191000
	66.345	0.09		48.60	48.60	191000
	66.346	5		48.63	48.65	191000
	66.347	0.09		51.09	51.09	191000
F-above Enfield Dam	66.414	360	50.7	50.67	50.67	193000
	66.427	65		50.73	50.73	193000
Route 190 Bridge	66.428	0.09		50.60	50.61	193000
low chord 78.9	66.435	37		50.66	50.66	193000
	66.436	0.09		51.02	51.03	193000
	66.449	70		51.08	51.07	193000
	67.113	3505		53.09	53.10	193000
	67.122	50		53.10	53.11	193000
Old Route 190	67.123	0.09		52.93	52.93	193000
Bridge Piers	67.128	26		52.94	52.94	193000
	67.129	0.09		53.40	53.41	193000
G	67.142	65	53.4	53.41	53.42	193000
H	67.944	4234	54.4	54.37	54.37	193000
I	68.679	3850	55.1	55.09	55.09	193000
	69.338	3479		55.74	55.74	193000

Remarks:

100 year elevations published in FIS for Enfield were adjusted to match Long Meadow, Mass.

Table 3. Comparison of FEMA published FIS floodway data and HEC-2 output

River Miles	East Bank Community	x-sec	FIS floodway (ft)				HEC-2 output (ft)			
			with	without	Increase	Width	with	without	Increase	Width
27.050	PORTLAND	A	20.8	21.5	0.9	1275	20.5	21.3	0.8	1275
27.947		B	20.9	21.8	0.9	840	20.9	21.7	0.8	840
28.465		C	21.0	21.9	0.9	750	21.2	22	0.8	741
28.920		D	21.8	22.7	0.9	3290	21.8	22.7	0.9	3290
29.825		E	22.1	23	0.9	1015	22.1	22.9	0.8	1015
30.427		F	22.4	23.2	0.8	1370	22.5	23.3	0.8	1370
31.025		G	22.9	23.8	0.9	1000	22.7	23.5	0.8	1000
31.555		I	23.1	23.9	0.8	1420	23.2	24	0.8	1420
32.030		J	23.3	24.1	0.8	1360	23.5	24.3	0.8	1360
32.800		K	23.8	24.6	0.8	1170	23.8	24.5	0.7	1170
33.400		L	24.1	24.8	0.7	1075	24.1	24.8	0.7	1075
34.734		M	25.0	25.9	0.9	1990	25	25.8	0.8	1990
35.462		O	25.0	26	1	885	25	26	1	885
36.562		P	26.3	27.2	0.9	1175	26.3	27.2	0.9	1175
37.080	GLASTONBURY	A	26.5	27.4	0.9	1190	26.5	27.4	0.9	1190
37.927		B	26.8	27.6	0.8	1370	26.8	27.7	0.9	1372
38.924		C	27.0	27.9	0.9	1330	27.3	28.1	0.8	1330
39.691		D	27.0	28	1	6800	27.6	28.5	0.9	6800
40.389		E	27.0	27.8	0.8	7810	27.7	28.6	0.9	7815
41.194		F	27.1	28	0.9	9500	27.8	28.7	0.9	9500
42.535		G	27.6	28.6	1	8200	27.8	28.7	0.9	8200
44.086		H	27.9	28.8	0.9	7110	27.9	28.8	0.9	7115
45.522		I	28.1	29.1	1	4500	28.1	29	0.9	4500
45.681		J	28.2	29.2	1	5415	28.3	29.2	0.9	4975
46.302		K	28.3	29.3	1	4985	28.4	29.3	0.9	4695
46.676	EAST HARTFORD	A	28.8	29.7	0.9	5190	28.5	29.4	0.9	4653
47.703		B	29.1	30.1	1	1040	28.5	29.5	1	1040
48.662		C	29.4	30.3	0.9	1270	28.9	29.9	1	1270
48.885		D	29.4	30.4	1	1125	29.1	29.9	0.8	1125
49.712		E	29.8	30.8	1	705	29.4	30	0.6	705
49.846		F	29.8	30.8	1	585	29.5	30.4	0.9	585
50.008		G	29.8	30.8	1	950	30	30.9	0.9	950
50.710		H	30.3	31.3	1	955	30.4	31.1	0.7	955
50.794		I	30.3	31.3	1	1100	30.5	31.4	0.9	1100
51.612		J	30.4	31.4	1	1890	30.8	31.7	0.9	1890
52.494		K	30.8	31.8	1	3620	31	32	1	3620
53.521	SOUTH WINDSOR	A	31.1	32.1	1	1160	31.2	32.1	0.9	1160
53.630		B	31.2	32.2	1	1275	31.3	32.2	0.9	1275
54.822		C	31.7	32.7	1	4700	31.8	32.8	1	4700
56.007		D	32.0	33	1	6200	32.1	33.1	1	6200
56.774		E	32.2	33.2	1	5300	32.2	33.2	1	5300
58.436	EAST WINDSOR	A	32.5	33.5	1	2450	32.6	33.4	0.8	2450
59.047		B	32.7	33.7	1	3250	32.8	33.7	0.9	3250
60.197		C	33.1	34.1	1	2050	33.2	34.1	0.9	2050
60.992		D	33.4	34.4	1	1400	33.5	34.4	0.9	1400
61.100		E	33.6	34.5	0.9	1200	33.7	34.5	0.8	1200
61.806		F	33.9	34.8	0.9	1175	33.9	34.8	0.9	1175
61.930		G	34.2	35.2	1	1225	34.3	35.2	0.9	1225
63.090	ENFIELD	A	35.7	36.7	1	1300	35.8	36.7	0.9	1300
64.040		B	37.8	38.5	0.7	1900	37.8	38.5	0.7	1900
64.770		C	39.0	39.6	0.6	955	39.1	39.6	0.5	955
65.357		D	42.9	43.1	0.2	810	43	43.1	0.1	810
66.160		E	49.4	49.5	0.1	1000	49.4	49.5	0.1	1000
66.414		F	50.7	50.8	0.1	1060	50.7	50.7	0	1060
67.142		G	53.4	53.5	0.1	1010	53.4	53.4	0	1010
67.944		H	54.4	54.5	0.1	1190	54.4	54.5	0.1	1190
68.679		I	55.1	55.2	0.1	1405	55.1	55.2	0.1	1405

Table 2 and discussed in the next two paragraphs.

The difference at cross-sections between the HEC-2 100-year flood elevations for this study versus the previous HEC-2 100 year flood elevations contained in the microfiche files (Anderson Nicholas studies) was insignificant. Differences at cross-sections ranged from 0 to 0.1 feet.

The difference between the HEC-2 100-year flood elevations for this study versus the values published in the Flood Insurance Studies for the communities was larger but not considered significant. Differences at cross-sections ranged from 0.0 to 0.7 feet. The differences between the published values and the HEC-2 100-year flood elevations may be caused by attempts to match elevations in adjacent communities. Matching elevations is standard procedure in the Flood Insurance Studies program providing for conformity along the river (See remarks included in Table 2.)

It was observed while compiling the model that computed water surface elevations are sensitive to the starting water surface elevation through East Windsor. This may be related to the relatively flat flood profile from Portland through East Windsor. The HEC-2 100-year flood profile is plotted on plates 6 and 7.

The Model is also run for the 100-year flow while confining the flow to specified encroachment stations. The computed water surface elevations and top width from this run and the information published in the FIS studies are compared in Table 3. The increase in water surface elevation when the flow is confined within the encroachment stations averages about one foot.

At the request of the State of Connecticut, the model was run at the States Encroachment Line Program design flow. This flood profile is shown on plates 5 and 6. Several of the cross-sections were extended by the model for calculation of the hydraulic properties of the cross-sections. The results of this run are compared in the following sentences to the flood profile published in the "Connecticut Stream Encroachment Lines" report. The computed water surface elevations are compared in the vicinity of bridges as these points are easily identifiable on the profile. From Portland to the Buckley Memorial Bridge in East Hartford the the HEC-2 output is approximately 0 to 2 feet less, from here to below the Enfield Dam the HEC-2 profile is approximately 1 to 3 feet greater, from Enfield dam to the state line the HEC-2 is approximately 4 feet less to 0.5 foot above . The HEC-2 surface water elevation at the state line is 62.6 feet and the elevation shown on the Connecticut stream encroachment profile is approximately 62 feet. The differences in the HEC-2 output and the previously calculated profile is not unexpected because of the different methodologies used for computation.

SUMMARY

A HEC-2 input file for the Connecticut River from Portland to Enfield is compiled and is available to the Connecticut DEP for their use.

LITERATURE REVIEWED

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2. State of Connecticut, Department of Environmental Protection, Water Resources Unit, Back-up for the HEC-2 Water Surface Profiles computer program set up by Anderson-Nichols, Inc.
3. Federal Emergency Management Agency, Federal Insurance Administration, Flood Insurance Studies for Portland (1978), Glastonbury (1977), East Hartford (1979), South Windsor (1988), East Windsor (1977), Enfield (1978), Middletown (1980), Cromwell (1977), Rocky Hill (1977), Wethersfield (1982), Hartford (1986), Windsor (1988), Windsor Locks (1977), and Suffield (1979).
4. State of Connecticut, Metropolitan District Commission, Topographic Maps, Scale 1:2400, Contour Interval 2 feet
5. Connecticut Water Resources Commission, Report on Stream Encroachment Lines - Connecticut River - Bodkin Rock to Massachusetts State Line, 1959.
6. U.S. Army Corps of Engineers, The Hydrologic Engineering Center, "HEC-2 Water Surface Profiles, Users Manual", September 1982.
7. U. S. Department of the Interior, Geological Survey, 7.5 Minute Series Topographic Maps, Scale 1:24000, Contour Interval 10 feet: Middletown (1984), Middle Haddam (1971), Hartford South (1972), Glastonbury (1984), Hartford North (1972), Manchester (1968), Windsor Locks (1984), Broad Brook (1984), West Springfield (1970), Springfield South (1958).
8. U. S. Department of the Army, Corps of Engineers, New England Division, Connecticut River Basin - Comprehensive Water and Related Land Resources Investigation, Volumes I, IV, and VIII, 1970.
9. U. S. Water Resources Council, "Guidelines for Determining Flood Flow Frequency," Bulletin #17B, March 1982.



NOTE:

1. Cross section locations are taken from Floodway maps published by FEMA under the National Flood Insurance Program. Cross sections included in FIS study but not shown on FEMA mapping are not included here.
2. Cross section numbers correspond to section numbering for HEC-2 input file.
3. Cross section location lines do not represent extent of ground points along cross section.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

**CONNECTICUT RIVER FLOOD INVESTIGATION
APPROXIMATE LOCATION OF
FIS CROSS SECTIONS**

FEBRUARY 1990

SCALE IN FEET
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CONTOUR INTERVAL 10 FEET



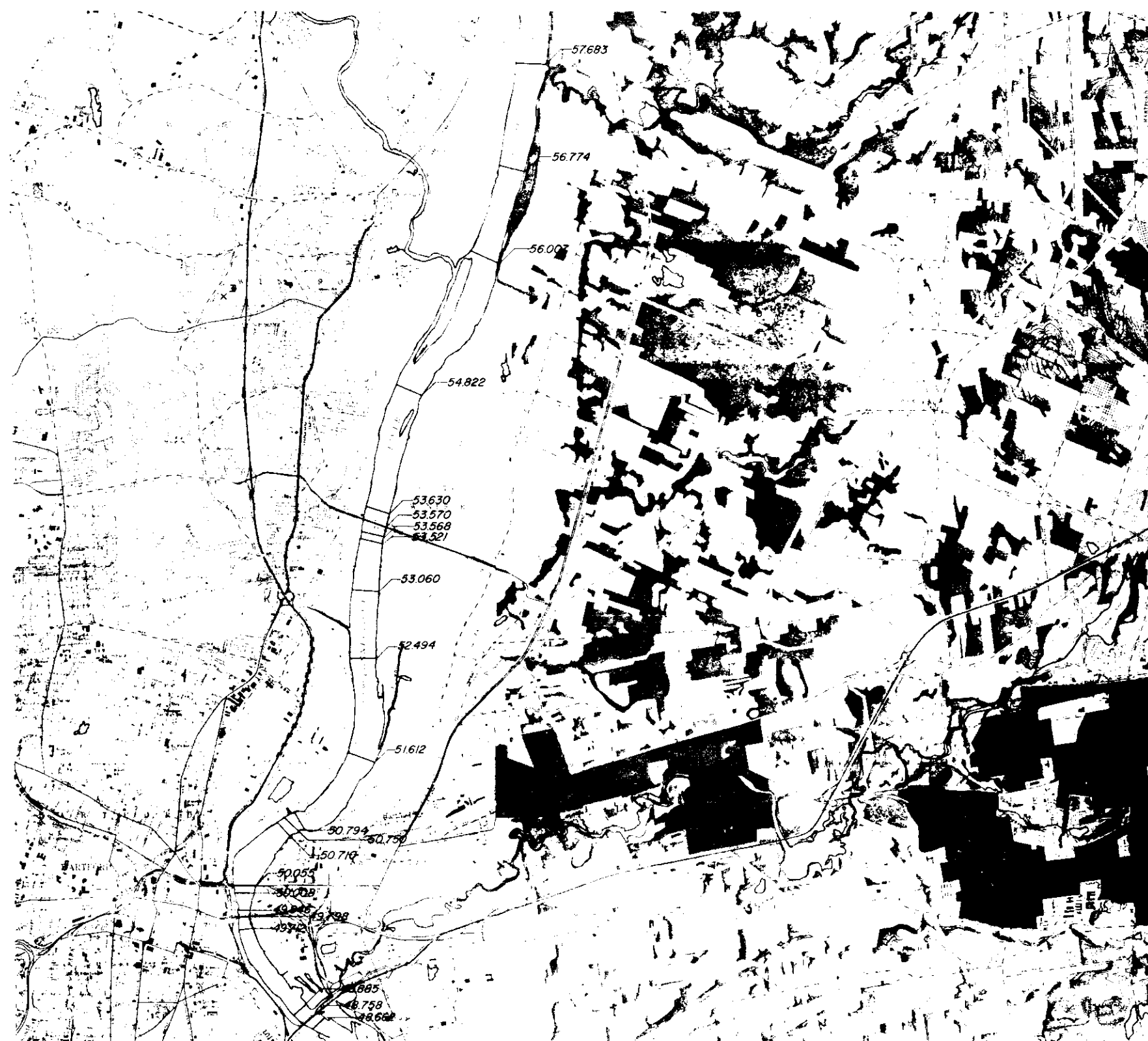
NOTE

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**CONNECTICUT RIVER FLOOD INVESTIGATION
APPROXIMATE LOCATION OF
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FEBRUARY 1990



NOTE:

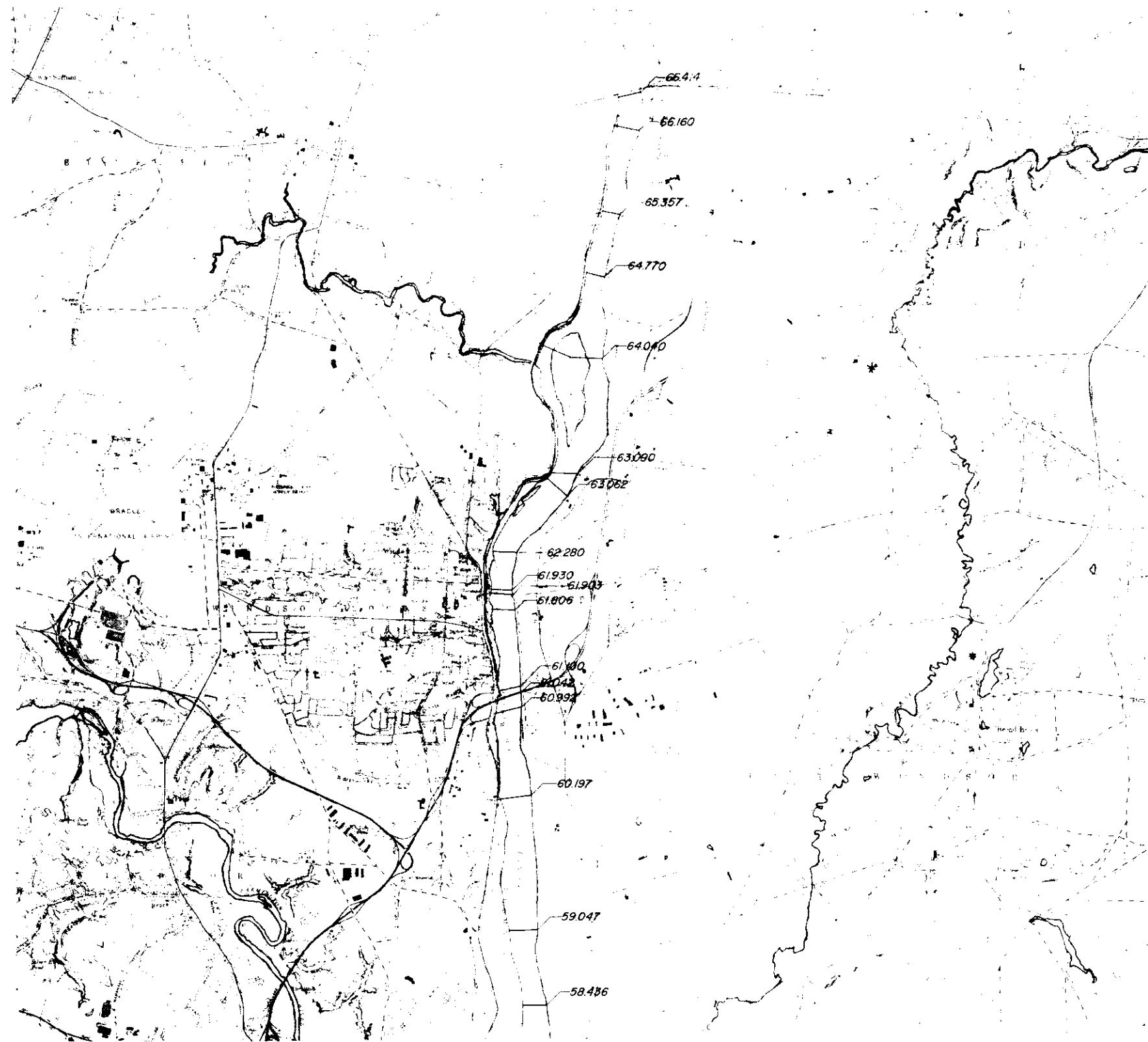
1. Cross section locations are taken from Floodway maps published by FEMA under the National Flood Insurance Program. Cross sections included in FIS study but not shown on FEMA mapping are not included here.
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SCALE IN FEET
2000 0 2000 4000
CONTOUR INTERVAL 10 FEET

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CONNECTICUT RIVER FLOOD INVESTIGATION
APPROXIMATE LOCATION OF
FIS CROSS SECTIONS

FEBRUARY 1990



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**CONNECTICUT RIVER FLOOD INVESTIGATION
APPROXIMATE LOCATION OF
FIS CROSS SECTIONS**

FEBRUARY 1990

SCALE IN FEET
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CONTOUR INTERVAL 10 FEET



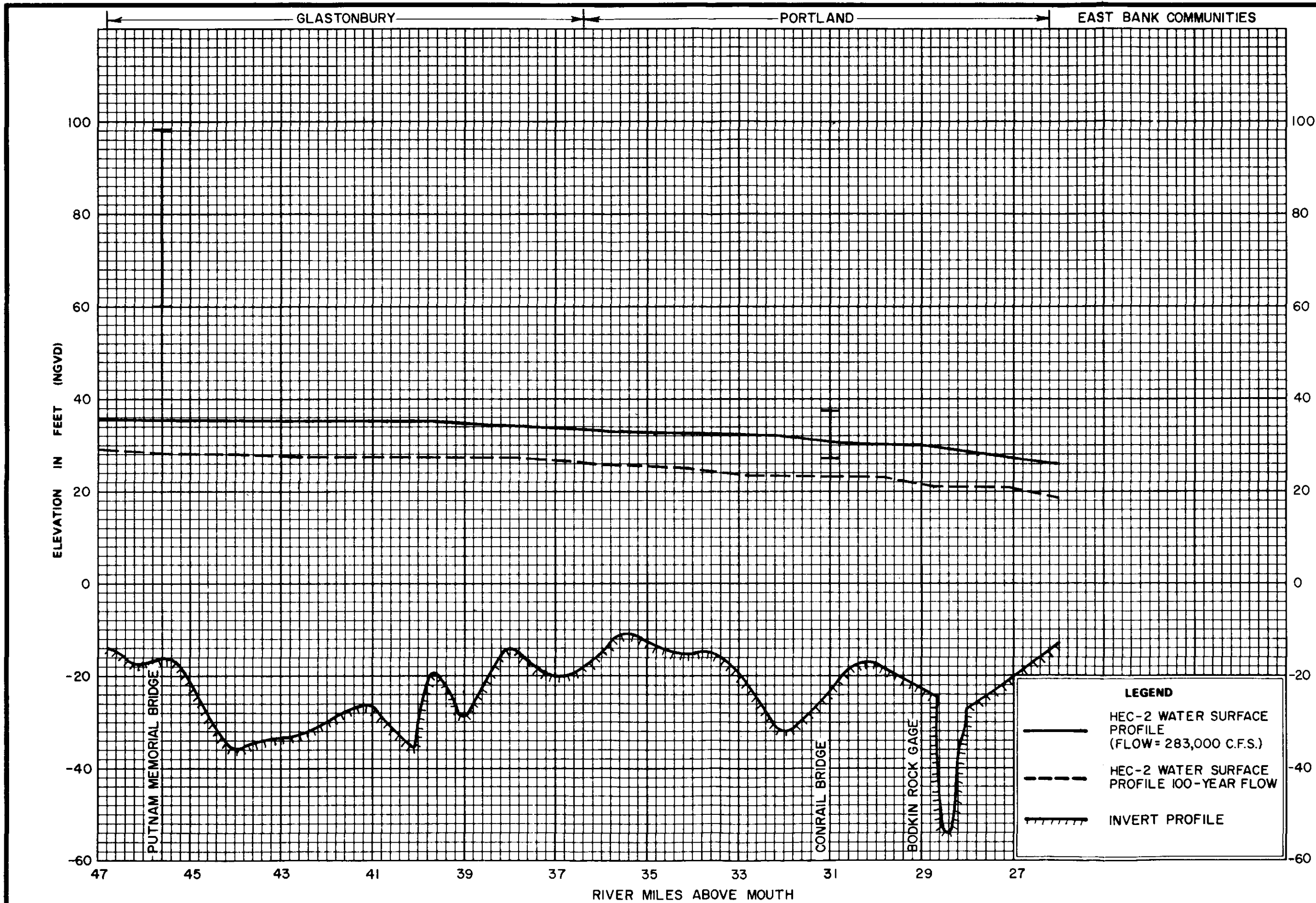
NOTE:

1. Cross section locations are taken from Floodway maps published by FEMA under the National Flood Insurance Program. Cross sections included in FIS study but not shown on FEMA mapping are not included here.
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3. Cross section location lines do not represent extent of ground points along cross section.

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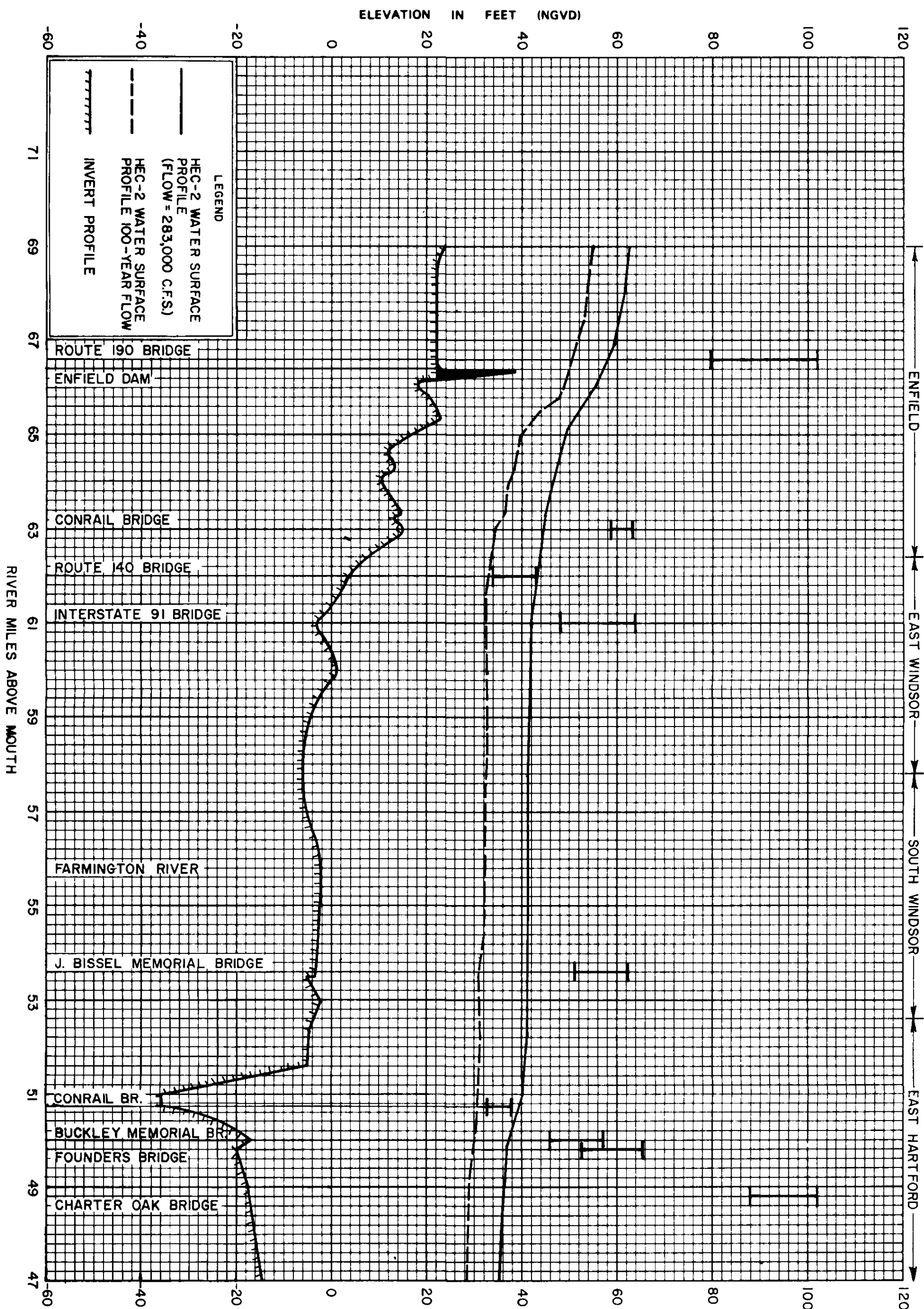
**CONNECTICUT RIVER FLOOD INVESTIGATION
APPROXIMATE LOCATION OF
FIS CROSS SECTIONS**

FEBRUARY 1990



U.S. ARMY CORPS OF ENGINEERS
PORTLAND
GLASTONBURY

FLOOD PROFILES
CONNECTICUT RIVER



APPENDIX A

Letter from New England Division to
Commissioner Department of Environmental Protection

FEB 3 1989

Planning Division
Basin Management Branch

Ms. Leslie Carothers, Commissioner
Department of Environmental Protection
165 Capitol Avenue
State Office Building
Hartford, Connecticut 06115

Dear Commissioner Carothers:

On November 28, 1988 representatives of the Corps of Engineers and members of the Connecticut Department of Environmental Protection met to discuss the scope of work for a Flood Plain Management Services (FPMS) investigation of the flooding problems along the Connecticut River. Mr. Alan Williams of your staff expressed concerns regarding proposed alterations by a private developer to the Corps-constructed East Hartford Dike. His concerns centered on the State's desire to insure the future structural integrity of the project, its continued operation and maintenance, and the role of the Corps of Engineers would have regarding any proposed modification to a Corps-constructed, locally operated and-maintained project. It was agreed at the meeting that my staff would look into this matter and provide the State with pertinent information.

The New England Division is aware of a proposed modification to the East Hartford Dike in which a developer would like to remove a portion of the earthen dike and replace it with a concrete wall. This project, as well as any future proposed alteration to a Corps of Engineers project, must be reviewed and approval granted by the New England Division. This office will not approve any plan for construction without the prior approval of the local sponsor and the State of Connecticut. The proposed alteration must retain the structural integrity of the project as defined by published Corps of Engineers Regulations. The responsibility for the maintenance and operation of the project and any modification will remain with the local sponsor. The Corps of Engineers inspects all local protection projects at least on an annual basis to insure the project's integrity and that it is functioning properly.

The New England Division recently began an investigation to review the adequacy of the protection afforded by the East Hartford Local Protection Project. Mr. Paul Albrecht of our Plan Formulation Branch is the project manager of this investigation. If you have any questions concerning the East Hartford Dike investigation please contact Mr. Albrecht at (617) 647-8381.

If you have any questions regarding this information please contact Ms. Barbara Notini at (617) 847-8544.

Sincerely,

Stanley J. Murphy
Lt. Colonel, Corps of Engineers
Acting Division Engineer

Copies Furnished:

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Natural Resources
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cf:

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Mr. Kennelly, 112N (willi)
LRPS, 112N
Mr. Manor, 106S
Mr. Albrecht, 114N
Reading File
BMB File, 112N
Ping Div File, 114S

APPENDIX B

REVIEW AND UPDATE OF
CONNECTICUT RIVER DISCHARGE FREQUENCIES
AT MIDDLETOWN, CONNECTICUT

PREPARED BY
THE HYDROLOGIC ENGINEERING SECTION
NEW ENGLAND DIVISION, CORPS OF ENGINEERS

REVIEW AND UPDATE OF
CONNECTICUT RIVER DISCHARGE FREQUENCIES
AT MIDDLETOWN, CONNECTICUT

1. PURPOSE

As part of the FPMS technical assistance program the State of Connecticut requested the Corps of Engineers review the previously developed peak discharge frequencies for the lower Connecticut River. This request resulted from recent flood events, namely, May/June 1984 and March/April 1987. The State felt these high flow events might affect lower Connecticut River discharge frequencies. The review documented in the following paragraphs was conducted using guidance contained in "Guidelines for Determining Flood Flow Frequency," Bulletin 17B, Interagency Advisory Committee on Water Control, March 1982.

2. FLOOD HISTORY

Damaging floods have been experienced on the Connecticut River and its tributaries since establishment of the first settlements in the basin. The USGS has recorded flows at Middletown dating back to the early 1800's. Reliable records of flood stages at Hartford have been kept since 1838 and information on the relative magnitude of flood stages at Hartford dates back to the 1600's.

The greatest flood of record on the lower Connecticut River was experienced in March 1936 when a stage of 37.0 feet NGVD was reached at the Hartford gage. The second greatest flood occurred in September 1938, with a level of 2.2 feet below the 1936 peak stage, and the third largest occurred in June 1984 when a peak elevation of 30.7 feet NGVD was experienced at the Hartford gage.

The Connecticut River through the Hartford area is located within the limits of a long storage reach; therefore, peak flood stages at Hartford are more a function of peak storage in the reach rather than peak flow in the river through Hartford. This storage creates a 'hysteresis effect' on the rating curve at Hartford, and due to the lack of a constant stage-discharge relationship at Hartford, the stages are related to peak flows at the Middletown gage, where flows are a function of maximum storage in the reach.

Historic flood levels at Hartford versus peak flows at Middletown are listed in table 1.

TABLE 1

HISTORIC FLOOD LEVELS
HARTFORD, CONNECTICUT

<u>Date</u>	Flood Level in Feet NGVD at <u>Memorial Bridge</u> (DA = 10,487 Sq.Mi.)	Discharge in CFS at USGS Gage <u>Middletown, CT</u> (DA = 10,887 Sq.Mi.)
Mar 1936	37.0	267,500
Sep 1938	34.8	239,000
Jun 1984	30.7	186,000
Aug 1955	30.0	188,000
May 1854	29.2	180,000
Nov 1927	28.4	172,000
Apr 1960	27.4	171,000
Apr 1987	25.6	140,500

3. FLOOD CONTROL

Since the great floods of March 1936 and September 1938, the Corps has constructed a system of 16 flood control reservoirs in the Connecticut River Basin, which control flood runoff from 1,570 square miles, or 15 percent of the Connecticut River watershed above Hartford. Typical flood reductions provided by the existing system of reservoirs will vary depending on the storm orientation with respect to the upstream reservoirs. Natural and modified discharges for the major historical floods, including June 1984 and April 1987, are listed in table 2.

4. DISCHARGE FREQUENCIES

a. Natural. Natural (unmodified by flood control reservoirs) discharge-frequency curves have been developed during past Corps of Engineers studies for key index stations along the main stem Connecticut River. Analysis of flow records at Middletown (Bodkin Rock) were made in the mid-1960's for the then available 123 years of systematic flow records plus records of historic flood events that occurred in 1683, 1692, 1801, and 1828. Discharge frequencies were determined using a Log Pearson Type III analysis with 127 years of flow data (123 years systematic and four historic events). Results of this analysis had a mean log of 5.008, standard deviation of 0.135, and a computed skew of about 0.0. Based on regional analysis a skew coefficient of 0.5 was adopted.

TABLE 2

EFFECT OF EXISTING RESERVOIRS ON FLOODS
OF RECORD, HARTFORD, CONNECTICUT

<u>Event</u>	<u>Natural</u> <u>Discharge**</u> (cfs)	Modified by 16 Existing Reservoirs*
		<u>Discharge</u> (cfs)
Mar 1936	267,500	206,100
Sep 1938	239,000	194,500
Jun 1984	220,000	186,000
Aug 1955	182,000	162,000+ (est)
Nov 1927	174,000	(Lack of sufficient
Apr 1960	171,000	data to determine)
Apr 1987	163,500	140,500

* Existing 16 reservoirs

** Discharges at USGS gage at Middletown, CT

As part of current studies this analysis was updated for the now available 147 years of systematic flow data (1838 - 1988) plus the 4 historic flood events for a total of 151 years of flow record. This longer period contained computed natural 1984 and 1987 peak flows (natural flows since completion of the upstream flood control reservoirs were determined by the Reservoir Control Center, New England Division, Corps of Engineers). This data was also analyzed in a Log Pearson Type III analysis resulting in a mean log of 5.000, standard deviation of 0.138, and a computed skew of about 0.0. As with previous studies a skew coefficient of 0.5 was adopted. Results of the analysis of the longer period of record, including the 1984 and 1987 computed natural flows, indicated less than a 1 percent increase in the peak 1 percent chance flood discharge as determined during the 1960's analysis. The remainder of the frequency curve was in very close agreement with the frequency curve computed in the 1960's. The adopted natural discharge frequency curve, based on the analysis of flow data up to 1988, is shown on attachment 1.

As a sensitivity test, assuming the 1984 and 1987 flood events had not occurred and the estimated annual flood event had occurred during those two years, computed discharge frequencies were determined. The computed natural 1984 and 1987 flood peak of 220,000 and 163,500 cfs, respectively, were replaced with the peak annual discharges of about 98,000 cfs and the Log Pearson Type III frequency analysis was conducted for this data set. The computed 1 percent chance discharge for this data set was only about 2 percent less than the computed 1 percent chance discharge using the entire period of record, including the natural 1984 and 1987 floodflows (235,000 versus 230,000 cfs).

As a final sensitivity test on the computed natural discharge frequencies, the three largest flood events (1936, 1938 and 1984) were identified as high outliers for the historic period of 306 years (1683 - 1988). The procedure to adjust for historic information as outlined in Bulletin 17B, "Guidelines for Determining Flood Flow Frequency, Appendix 6 was used and natural discharge frequencies were computed. The HEC "Flood Flow Frequency Analysis" computer program was used to aid in the analysis. By identifying the three largest flood events as high outliers and extending the period of record to 300+ years the resulting effect on the computed natural 1 percent chance discharge was to reduce it about 4 percent (235,000 versus 226,000 cfs).

Considering the sensitivity tests conducted and the relatively small effect on computed natural discharge frequencies the discharge frequency curve shown in attachment 1 which is

based on analysis of the entire historic period (150 years of flow data) is considered reasonable.

For a graphical check of the computed discharge frequency curve, plotting positions were assigned to the observed data. Analysis of historic flow data indicates that the 1936, 1938 and 1984 floods were the three largest during the period of record (300+ years). Therefore, the adopted Weibull plotting position for the 1936 flood for this analysis is 0.003 (1/300 years). The 1938 and 1984 flood discharges were assigned 0.006 (2/300) and .01 (3/300), respectively.

Due to the difference in magnitude between the three major floods (1936, 1938 and 1984) and the remainder of the data, the plotting positions for the remaining flood events were determined assuming a period where systematic records were kept about 150 years. The computed discharge frequency curve with plotted data is shown on attachment 1.

b. Modified. Modified discharge frequencies were developed to reflect conditions with the present system of Corps flood control reservoirs with the resulting curve shown on attachment 1. The reductions shown are based on analysis of the "Typical Tributary Contribution Flood" (TTCF) which was developed by the New England Division, Corps of Engineers. In general, this analysis technique was to develop a typical distribution or average flood over the basin and then, by studying multiples of this flood, determine the typical effectiveness of a flood control system for a wide range of flood frequencies. Using this method TTCF hydrographs are developed for all tributaries and are combined and routed downstream to determine the typical contribution of the tributary flows to flood peaks at damage centers. It should not be inferred that for every occurrence of a certain frequency flood at the Middletown gage the reduction will be as shown on the modified discharge frequency curve. Some reductions will be greater and some less, depending on the storm orientation with respect to the upstream reservoirs. The adopted modified frequency curve represents the expected average reduction for a wide range of floods and is used to provide a hydrologic basis for economic analysis of flood control measures. The average reduction in peak discharges at Middletown by the existing system of Corps reservoirs is ~~considered~~ approximately 21 percent. Also shown are natural and modified discharges for the 1936, 1938, 1984, and 1987 flood events along with the estimated modified August 1955 flood discharge. As can be seen, based on the modified discharges for the five historic floods analyzed and their adopted Weibull plotting positions, there is close agreement with the modified discharge frequency curve.

To check the sensitivity of the adopted modified discharge frequencies, the period of record since the last Corps of Engineers flood control reservoir was placed in operation was analyzed. The final Corps reservoir went into operation in 1969; therefore, the period from 1970 to 1988 (19 years) was analyzed. Results of the Log Pearson Type III analysis had a mean log of 4.9655, standard deviation of 0.117, and a computed skew of 0.76. The previously determined regional skew of 0.5 was adopted. This analysis was compared with the modified discharge frequency curve shown on attachment 1. Results of analysis of the last 19 years of flow data indicate a 1 percent chance discharge about 3 percent greater than the modified discharge frequency curve shown on attachment 1. It is recognized that during this period the large 1984 flood event was experienced and has a notable effect on a short period of record (19 years).

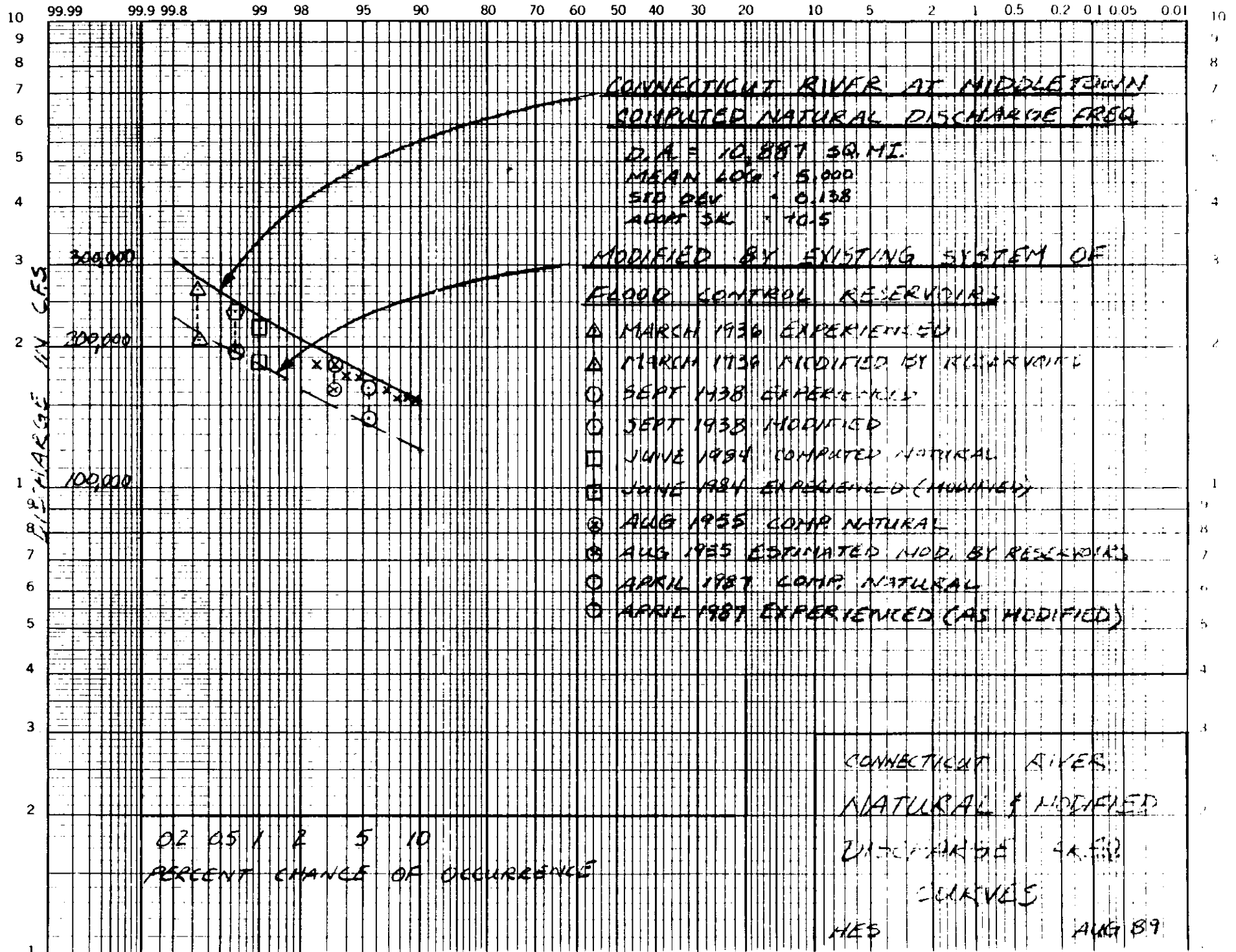
Based on analysis conducted, the adopted modified discharge frequency curve is considered reasonable.

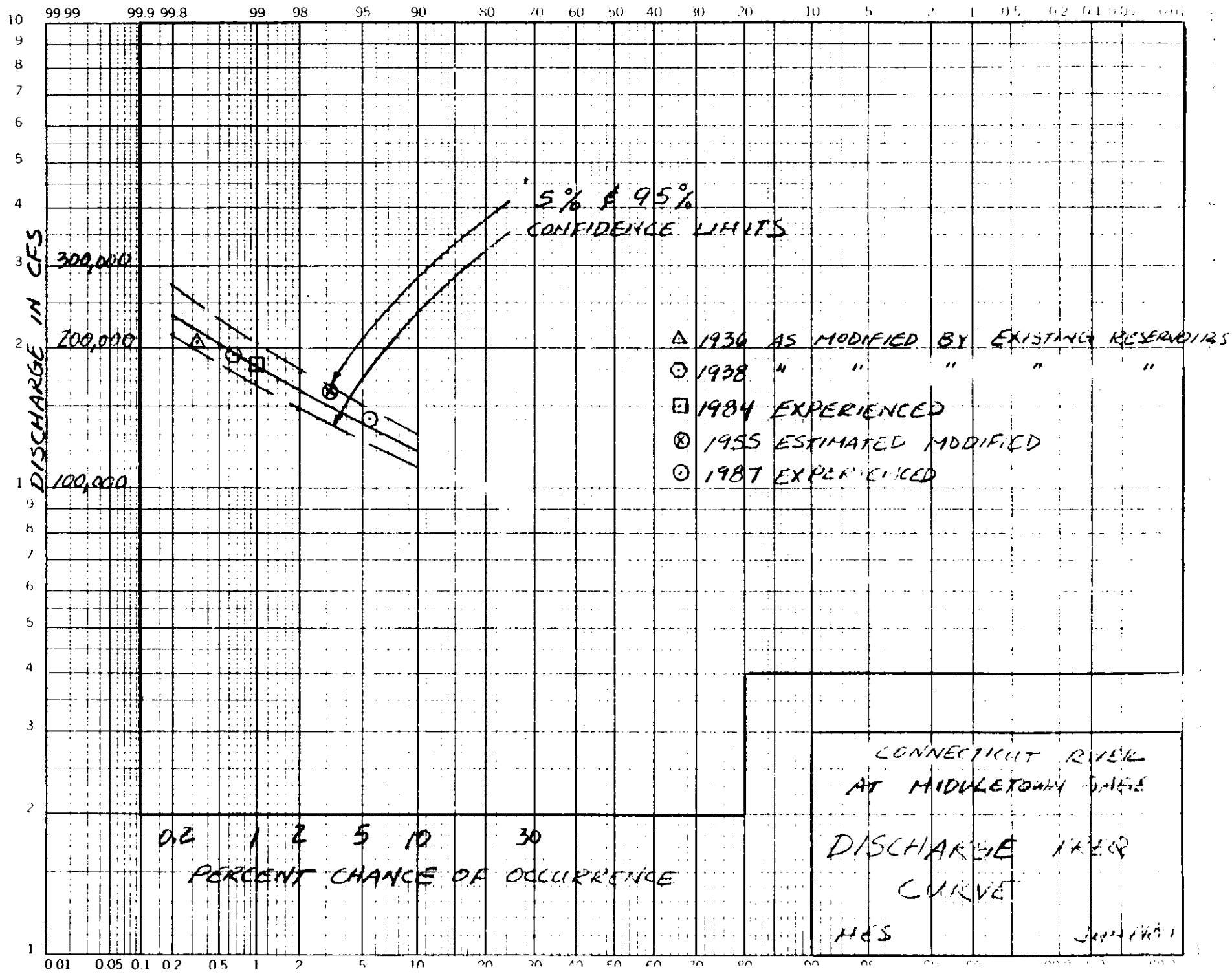
5. UNCERTAINTY AND SENSITIVITY OF DATA

Establishing the frequency and magnitude of abnormal hydrologic events is not an exact science. Projecting the frequency and magnitude of peak flood discharges is generally accomplished by statistical analysis of experienced flow history. Obviously what has happened in the past is not a precise indicator of what may, or can, happen in the future. Secondly, for any magnitude of floodflow at a point on a river there is an infinite number of upstream storm and runoff conditions that could produce that discharge. For this reason the relative effectiveness of a system of reservoirs can vary and therefore the reduction in peak flow is taken as an average based on analysis of a typical flood as described previously. Peak discharges as well as uncertainty can be estimated using statistics. Reference: "Guidelines for Determining Flood Flow Frequency," Bulletin 17B, Interagency Committee on Water Data, March 1982. However, an estimated flood frequency curve can be only an approximation based on the data set analyzed. As a measure of the accuracy of a computed frequency, confidence limits can be constructed. The 5 and 95 percent confidence limits of the computed natural Connecticut River discharge frequency curve at Middletown have been determined. Assuming that the discharge frequency curve, as modified by reservoirs, would have the same percent derivation in peak flows in the 5 and 95 percent confidence intervals as the natural curve, the confidence limits were estimated for the modified curve as shown on attachment 2.

6. SUMMARY/CONCLUSION

In summary, the statistical confidence or uncertainty analysis indicated there is a 95 percent probability that the 100-year discharge at Middletown is greater than 170,000 cfs and a 95 percent probability that it is not greater than 205,000 cfs. The previously developed modified 100-year discharge of 185,000+ cfs at Middletown is midway between the computed confidence limits. The modified discharge frequency curve developed in this current study is considered hydrologically similar to the frequency curve developed in the 1960's. The occurrence of the 1984 and 1987 floods in recent years has had no significant impact on the long term flow frequency relationship at the Middletown gage.





APPENDIX C

BACKGROUND ON HEC-2

This is a brief description of the HEC-2 model included for those not familiar with the model and required input data. A more detailed description is found in the HEC-2 Water Surface Profiles, Users Manual, 1982.

HEC-2 was developed by the U. S. Army Corps of Engineers, Hydrologic Engineering Center in Davis, California. The HEC-2 program is used for calculating water surface profiles for steady gradually varied flow in natural or man-made channels. The effects of bridges and dams which may obstruct flow are considered in the computations. The HEC-2 model is used extensively as a tool in the estimation of flood elevations in rivers and streams for a selected flood flow event. The program is also designed for application in floodplain management to evaluate floodway encroachment.

The input data needed to compute water surface elevations along the river (profiles) includes: flow regime, starting water surface elevation, discharge values, loss coefficients, cross section geometry, and reach lengths.

Profile computations begin at a cross section with known or assumed starting condition and proceed upstream for subcritical flow and downstream for supercritical flow. Some type of knowledge of the starting water surface elevation for the beginning cross section is required and can be input as a known starting water surface elevation. Starting discharge at the beginning cross section must also be specified and discharges can be changed at selected cross sections in the data set.

Several types of loss coefficients can also be utilized by the program to evaluate head loss including Manning's 'n' values for friction loss, contraction and expansion coefficients to evaluate transition losses, bridge loss coefficients to evaluate losses related to weir shape, pier configuration, and pressure flow.

Boundary geometry for the analysis of flow in the stream is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths). The cross sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent flood plains. The cross sections should accurately represent the stream and flood plain geometry, however, ineffective flow areas of the flood plain, such as stream inlets, small ponds, or indents in the valley floor, should not be included. Cross section data is traditionally oriented looking downstream since the program considers the left side of the stream to have the lowest station numbers and the right side to have the highest.

Cross sections located at bridges are modeled differently than cross section in the open channel. The normal bridge method, which uses the standard step method for computing losses, is usually used in cases where the bridges and abutments are a small obstruction to the flow. The special bridge method is usually used where the bridge is submerged and acts as a weir. This method can also be used to model dams.